

## CLAIMS

What is claimed is:

1. A crystal puller for growing monocrystalline ingots according to the Czochralski method, the puller comprising:
  - a housing;
  - a crucible in the housing for containing a semiconductor source material
  - 5 melt, the melt having an upper surface;
  - a side heater adjacent the crucible for heating the crucible;
  - a pulling mechanism for pulling a growing ingot upward from the upper surface of the melt, a portion of the upper surface of the melt remaining exposed during growing of the ingot, the exposed upper surface portion having an area;
  - 10 and
  - an annular melt heat exchanger sized and shaped for surrounding the ingot and for being disposed adjacent the exposed upper surface portion of the melt, the heat exchanger including a heat source disposed to face the exposed upper surface portion of the melt, the heat source having an area for radiating
  - 15 heat to the melt sized at least 30% of the area of the exposed upper surface portion of the melt for controlling heat transfer at the upper surface of the melt, the melt heat exchanger being adapted to reduce heat loss at the exposed upper surface portion.
2. A crystal puller as set forth in claim 1 wherein the heat source has an area sized at least 40% of the area of the exposed upper surface portion of the melt.
3. A crystal puller as set forth in claim 1 wherein the heat source has an area sized at least 50% of the area of the exposed upper surface portion of the melt.
4. A crystal puller as set forth in claim 1 wherein the heat source has an area sized at least 60% of the area of the exposed upper surface portion of the melt.

5. A crystal puller as set forth in claim 1 wherein the heat source is adapted to be disposed within 50mm of the exposed surface of the melt.

6. A crystal puller as set forth in claim 1 wherein the heat source is adapted to be disposed within 30mm of the exposed surface of the melt.

7. A crystal puller as set forth in claim 1 further comprising a reflector supporting the melt heat exchanger.

8. A crystal puller as set forth in claim 7 wherein the reflector includes insulation interposed between the melt heat exchanger and the melt.

9. A crystal puller as set forth in claim 8 further comprising a crystal heat exchanger sized and shaped to be disposed above the melt and substantially surround the ingot for cooling a first portion of the growing ingot proximate a melt/crystal interface.

10. A crystal puller as set forth in claim 9 further comprising a lower crystal heater disposed above the crystal heat exchanger and adapted for substantially surrounding the ingot for maintaining a second segment of the ingot at a predetermined temperature.

11. A crystal puller as set forth in claim 10 wherein the crystal heat exchanger and the lower crystal heater are mounted in the reflector, the reflector further comprising insulation disposed between the crystal heat exchanger and the ingot and between the lower crystal heater and the housing.

12. A crystal puller as set forth in claim 10 further comprising an upper crystal heater disposed above the lower crystal heater and substantially surrounding the ingot for maintaining a third segment of the ingot at a predetermined temperature.

13. A reflector assembly for use in a crystal puller for growing a monocrystalline ingot from a semiconductor source material melt, the crystal puller having a housing, a crucible contained in the housing for holding the source material melt, a heater in thermal communication with the crucible for heating the crucible to a temperature sufficient to melt the semiconductor source material held by the crucible and a pulling mechanism positioned above the crucible for pulling the ingot from the melt, the reflector assembly comprising:

a cover disposed above the melt and having a central opening sized and shaped for surrounding the ingot as the ingot is pulled from the melt:

10 a crystal heat exchanger at least partially inside the cover and adapted to be disposed above the melt and substantially surround the ingot for cooling a first segment of the growing ingot that is adjacent the melt/crystal interface; and

a melt heat exchanger at least partially inside the cover adapted to surround the ingot proximate the surface of the melt for controlling heat transfer at

15 the surface of the melt, the melt heat exchanger being adapted to reduce heat loss at the uncovered surface.

14. A heat shield assembly as set forth in claim 13 further comprising a lower crystal heater disposed above the crystal heat exchanger and substantially surrounding the ingot for maintaining a second segment of the ingot at a predetermined temperature.

15. A crystal puller as set forth in claim 13 wherein the reflector includes insulation interposed between the melt heat exchanger and the melt.

16. A crystal puller as set forth in claim 15 wherein the reflector includes insulation interposed between the melt heat exchanger and the crystal heat exchanger.

17. A reflector for use in a crystal puller for growing a monocrystalline ingot from a semiconductor source material melt, the crystal puller having a housing, a crucible contained in the housing for holding the source material melt, a heater in thermal communication with the crucible for heating the crucible to a

5 temperature sufficient to melt the semiconductor source material held by the crucible and a pulling mechanism positioned above the crucible for pulling the ingot from the melt, the reflector being disposed above the melt and having a central opening sized and shaped for surrounding the ingot as the ingot is pulled from the melt, the reflector comprising:

10 a crystal heat exchanger sized and shaped for placement above the melt and substantially surrounding the ingot for cooling a first segment of the growing ingot proximate a melt/crystal interface.

18. A heat shield assembly as set forth in claim 17 further comprising a lower crystal heater disposed above the crystal heat exchanger and substantially surrounding the ingot for maintaining a second segment of the ingot at a predetermined temperature.

19. A crystal puller as set forth in claim 18 further comprising an upper crystal heater disposed above the lower crystal heater and substantially surrounding the ingot for maintaining a third segment of the ingot at a predetermined temperature.

20. A crystal puller for growing monocrystalline ingots according to the Czochralski method, the puller comprising:

a housing;

5 a crucible in the housing for containing a semiconductor source material melt, the melt having an upper surface;

a side heater adjacent the crucible for heating the crucible;

10 a pulling mechanism for pulling a growing ingot upward from the upper surface of the melt, a portion of the upper surface of the melt remaining exposed during growing of the ingot, the exposed upper surface portion having an area; and

a reflector including an annular melt heat exchanger sized and shaped for surrounding the ingot and for being disposed adjacent the exposed upper surface portion of the melt, the heat exchanger including a heat source adapted to be disposed to face the exposed upper surface portion of the melt and to be within

15 50 mm of the exposed upper surface portion of the melt, the heat source having  
an area sized at least 40% of the area of the exposed upper surface portion of the  
melt for controlling heat transfer at the upper surface of the melt, the melt heat  
exchanger being adapted to reduce heat loss at the exposed upper surface  
portion and a crystal heat exchanger sized and shaped to be disposed above the  
20 melt and substantially surround the ingot for cooling a first segment of the growing  
ingot.

21. A method of growing a monocrystalline ingot comprising forming a melt  
of semiconductor source material in a crucible, the melt having a surface;  
positioning a heat source to face the exposed upper surface portion of the  
melt, the heat source having an area for radiating heat to the melt sized at least  
5 30% of the area of the exposed upper surface portion of the melt  
pulling semiconductor source material from the surface of the melt such  
that the source material solidifies into a monocrystalline ingot;  
selectively controlling heat transfer at the surface of the melt using the heat  
source.

22. A method as set forth in claim 21 wherein said step of selectively  
controlling heat transfer includes cooperatively controlling heat transfer at the melt  
surface and the application of heat to the melt surface by positioning the heat  
source within 100 mm of the melt surface to selectively control defects within the  
5 ingot.

23. A method as set forth in claim 22 wherein the melt/ingot interface has  
a shape, the selective controlling step including varying the heat radiated from the  
melt heat exchanger to control the interface shape.

24. A method as set forth in claim 23 further comprising removing heat  
from the ingot at a location above a melt/ingot interface using a crystal heat  
exchanger.

25. A method as set forth in claim 24 wherein the heat removal step includes controlling the temperature of cooling fluid in the crystal heat exchanger to remove heat from the ingot at a predetermined rate and to maintain the ingot above a predetermined temperature.

26. A method as set forth in claim 25 further comprising allowing a portion of the ingot above the crystal heat exchanger to cool at a rate greater than the predetermined rate to control formation and/or growth of defects within the ingot.

27. A method as set forth in claim 24 wherein the selective control step includes controlling the temperature of the melt heat exchanger such that a segment of the ingot near the interface is cooled at a predetermined rate to form excess self-interstitials and to inhibit formation of significant microdefects, the  
5 method further comprising removing heat from another segment of the ingot spaced from the interface at a rate greater than the predetermined rate to control formation and/or growth of agglomerated interstitial defects.

28. A method as set forth in claim 27 wherein the selective control step includes controlling the temperature of the melt heat exchanger such that a segment of the ingot near the interface is cooled at a predetermined rate to form excess vacancies and to inhibit formation of significant microdefects, the method  
5 further comprising removing heat from another segment of the ingot spaced from the interface at a rate greater than the predetermined rate to control formation and/or growth of agglomerated vacancy defects.

29. A method as set forth in claim 24 further comprising heating a segment of the ingot spaced from the melt/crystal interface using a lower crystal heater disposed above the crystal heat exchanger.

30. A method as set forth in claim 29 further comprising heating a segment of the ingot spaced from the melt/crystal interface using an upper crystal heater disposed above the lower crystal heater.

31. A method as set forth in claim 21 wherein the method is free of a step of removing or adding a structural component of the crystal puller.

32. A method of growing a monocrystalline ingot using a crystal puller including a housing, a crucible in the housing for containing a semiconductor source material melt having a surface, a side heater adjacent the crucible for heating the crucible, and a melt heat exchanger facing at least 30% of an  
5 exposed portion of the melt surface for heating the exposed portion, the method comprising:  
pulling the growing ingot upward from the melt, a melt/ingot interface being formed generally at a juncture of the ingot and the melt surface,  
controlling the temperatures of the melt heat exchanger and the side  
10 heater to control formation of defects within the ingot.

33. A method as set forth in claim 32 wherein the controlling step includes controlling the side heater power in a predetermined range such that the temperature of the crucible is maintained below a predetermined temperature.

34. A method as set forth in claim 33 wherein the controlling step includes reducing heat loss from the melt surface and simultaneously reducing the side heater temperature so as to reduce the temperature of the crucible.

35. A method as set forth in claim 32 wherein the melt/ingot interface has a shape, the controlling step including selecting a temperature of the melt heat exchanger to control the interface shape.

36. A method as set forth in claim 32 wherein the controlling step includes manipulating a temperature field at the melt/ingot interface.

37. A method as set forth in claim 32 further comprising selecting a desired axial temperature gradient, the controlling step including selecting a temperature of the melt heat exchanger to maintain the desired axial temperature gradient.

38. A method as set forth in claim 32 further comprising removing heat from the ingot at a location above the melt/ingot interface using a crystal heat exchanger.

39. A method of growing a monocrystalline ingot using a crystal puller including a housing, a crucible in the housing for containing a semiconductor source material melt having an upper surface, a side heater adjacent the crucible for heating the crucible, a pulling mechanism for pulling a growing ingot upward  
5 from the melt, a melt/crystal interface being formed generally at the upper surface of the melt and having a shape, an annular melt heat exchanger including a heat source having an area for radiating heat to the melt sized at least 30% of the area of an exposed upper surface portion of the melt, a crystal heat exchanger surrounding the ingot and facing the ingot for removing heat from the ingot  
10 adjacent the melt/crystal interface, the method comprising:  
pulling the growing ingot upward from the melt; and  
controlling an axial temperature gradient at the interface by manipulating a temperature field at the melt/ingot interface.

40. A method as set forth in claim 39 wherein the controlling step includes varying heat radiated from the melt heat exchanger and removing heat from the crystal using the crystal heat exchanger.

41. A method as set forth in claim 39 wherein the controlling step includes manipulating the temperature field to affect the shape of the interface.

42. A method as set forth in claim 39 wherein the controlling step includes manipulating heat radiated from a lower heater disposed above the crystal heat exchanger to control formation of defects in the growing ingot.

43. A method as set forth in claim 42 further comprising controlling heat radiated from an upper heater disposed above the lower heater to control formation and/or growth of defects in the growing ingot.

44. A method of growing a monocrystalline ingot using a crystal puller including a housing, a crucible in the housing for containing a semiconductor source material melt having a surface, a side heater adjacent the crucible for heating the crucible, a melt heat exchanger surrounding the ingot and facing an exposed portion of the melt surface, the melt heat exchanger including a heat source having an area for radiating heat to the melt sized at least 30% of the area of an exposed upper surface portion of the melt for heating the exposed portion, a lower heater for surrounding the growing ingot the method comprising:
- 5       pulling the growing ingot upward from the melt, a melt/ingot interface being
- 10      formed generally at a juncture of the ingot and the melt surface,
- controlling heat radiated from the melt heat exchanger and the side heater to control the interface shape; and
- controlling heat radiated from the lower heater to control the thermal history of segments of the growing ingot.

45. A method as set forth in claim 44 further comprising controlling heat removed from the crystal by a crystal heat exchanger disposed to surround a segment of the ingot above the interface.

46. A method as set forth in claim 45 further comprising controlling heat radiated from an upper heater disposed above the lower heater for further controlling the thermal history of segments of the growing ingot.